United States Air Force Scientific Advisory Board

Report on

Global Air Navigation Systems

Volume 1: Summary

SAB-TR-97-02

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ABSTRACT (Maximum 200 words)

Changes in global civil airspace architecture will necessitate changes in Air Force equipment and procedures. The Scientific Advisory Board Global Air Navigation Study attempted to identify, define, and categorize the modifications and additions necessary for Department of Defense (DOD) aircraft and ground systems to operate in the new environment in terms of urgency and utility. Many estimates of the cost of the new capabilities have been generated, and some of the estimates exceed $15 billion for all options. We believe that these estimates are not credible, and we propose an approach that is substantially less expensive. We also attempted to identify systems and technologies that can serve both military and civil needs. Participants in the study were drawn from a broad cross section of both civil and military aviation. We visited several military and civil aviation facilities, and took many briefings from and held discussions with U.S. and foreign government and commercial organizations.

The GANS study examined the needs and possibilities for navigation systems to be used by the USAF of the 21st century. Departure, en route, and landing procedures and requirements were studied. It should be noted that GATM requirements will affect not only aircraft but space and ground systems as well.

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Foreword

This volume summarizes the deliberations and conclusions of the 1997 USAF Scientific Advisory Board (SAB) Ad Hoc Study "Global Air Navigation Systems" (GANS).

This discussion will treat the long-term, most expensive issues first. Shorter-term, unavoidable modifications to existing systems will be discussed at the end of this paper. We have tried to provide an objective view of what is often a controversial subject.

The reader of this report should keep in mind that where recommendations to delay implementation are made in many places, eventual upgrades in capabilities are not themselves negotiable. Only the implementation methods and schedules are negotiable.

The Board wishes to thank the many individuals who contributed to the deliberations and the report. In addition to the Board members, many ad hoc members devoted their time. Industry assisted, and USAF Major Air Command liaison officers were extremely helpful. The USAF Academy provided technical writing assistance, which was most important. Special recognition goes to the SAB Secretariat staff and the ANSER team for their administrative assistance.

Finally, this report reflects the collective judgment of the SAB and hence is not to be viewed as the official position of the United States Air Force.

Dr. Gene H. McCall
Study Director

December 1997

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Executive Summary

Changes in global civil airspace architecture will necessitate changes in Air Force equipment and procedures. The Scientific Advisory Board Global Air Navigation Study attempted to identify, define, and categorize the modifications and additions necessary for Department of Defense (DOD) aircraft and ground systems to operate in the new environment in terms of urgency and utility. Many estimates of the cost of the new capabilities have been generated, and some of the estimates exceed $15 billion for all options. We believe that these estimates are not credible, and we propose an approach that is substantially less expensive. We also attempted to identify systems and technologies that can serve both military and civil needs. Participants in the study were drawn from a broad cross section of both civil and military aviation. We visited several military and civil aviation facilities, and took many briefings from and held discussions with U.S. and foreign government and commercial organizations.

Airspace architectures and global air traffic management (GATM) procedures are changing for several reasons. The density of air traffic in many parts of the world is increasing rapidly. Increasing passenger and flight volumes will force air traffic control (ATC) systems to handle volumes of traffic well beyond those for which they were designed. Some estimates predict that the existing global ATC system will become hopelessly overloaded shortly after the first decade of the 21st century. Safety is already an issue — perceived if not real — and increases in air traffic will produce increases in the number of accidents per year even if the accident rate remains constant. Efficiency of operation is always an airline concern, and the influence of this concern over national aviation authorities is increasing. It should always be remembered, however, that the Air Force exists to fight and win the Nation's wars. This mission must not be compromised in an attempt to satisfy civil airspace requirements.

Everyone's view of the future is, at best, murky. Considerations of density, efficiency, and safety can be used as general guidelines, however. Airline and USAF considerations are not necessarily different. After safety, the first decision metric used by an airline is return on investment (ROI). The important parameters that determine ROI differ among airlines, and USAF considerations may sometimes be different from those of all airlines, but ROI is closely related to efficiency of operation. Although the USAF is for the most part an unscheduled cargo airline, and its efficiency criteria are different from those of scheduled passenger airlines, many USAF flights operate during peak civil hours. The effect on the USAF of failure to comply with new civil navigation and communication standards is usually stated in negative terms. One study, for example, indicates that a 1.5-hour ATC delay per flight in a future Desert Shield scenario could increase the time to force closure by 50 percent, or 42 days. It should also be noted, however, that compliance will reduce fuel, flying hours, and the number of crews and will increase aircraft utilization.

Yet uncertain implementation plans for future international airspace architectures, especially the timing of required compliance, have made it difficult to persuade decisionmakers to fund GATM. A perceived lack of urgency and the implied existence of waivers for state aircraft have exacerbated the problem. High-priority military issues compete for limited funds. In the past we have resisted or ignored similar challenges until the threat of airspace exclusion or an accident involving loss of life forced an emergency reaction: equipping essential aircraft. These reactions were accompanied by the added expense of rushed procurement and integration. Current funding limitations make it imperative that we not repeat these mistakes. The Department of Defense operates

15,000 aircraft. All of them will be affected by changes in airspace architecture over the next 15 years. Although there is, indeed, much uncertainty in implementation plans for future airspace architectures, we found more definitive requirements than we expected. Specific requirements and dates will be discussed at the end of this paper in the section on short-term considerations.

The safety issue is one that the USAF must address in cooperation with civil aviation organizations. Controlled flight into terrain (CFIT) is a significant problem for the USAF. The T-43 “Ron Brown” crash in Croatia is probably the most publicized, but other events are troubling. The CFIT by a USAF C-130 at Jackson Hole, Wyoming; the A-10 crash in Arizona; and, perhaps, the recent B-1 low-level accident are all indications that more attention must be paid to CFIT. The civil community was galvanized by the American Airlines CFIT in Cali, Colombia; by another American Airlines incident at Hartford, Connecticut; and by the recent KAL accident in Guam. In the past five years, civil aviation has incurred more than 40 CFIT accidents at the cost of more than 2,000 lives. Perhaps the most emotional issue for the public, though, is midair collision (MAC). Close encounters between USAF aircraft and civilian airliners in the Northeast received much notice. The apparent collision between a C-141 and a German Air Force aircraft off the coast of Namibia also has been widely reported. Modern technology has matured to the point where CFIT and MAC need never occur. The issues are cost and implementation method.

It is unlikely that all USAF combat aircraft can comply with all future international regulations. It will be necessary to conduct some “fighter drag” operations in which combat aircraft are accompanied by GATM-qualified aircraft. There will be emergency situations in which aircraft will proceed with “due regard.” Contingency planning should be done for these operations. However, it should be the goal of the USAF to *use warfighting capabilities to guarantee rapid, unrestricted global access for all United States weapon systems*. Where possible, airspace requirements should be satisfied by systems that also enable military capabilities.

Rapid, unrestricted global access requires capabilities beyond those necessary for normal flight in civil airspace. For example, military aircraft must operate from austere airbases that are not equipped for all-weather civil operations. The difficulties encountered in operating into Tuzla at the beginning of the Bosnia operation are well known. The USAF response to the C-17’s shortcomings in this case was short term, technically unsatisfying, and expensive.

The GANS study examined the needs and possibilities for navigation systems to be used by the USAF of the 21st century. Departure, en route, and landing procedures and requirements were studied. It should be noted that GATM requirements will affect not only aircraft but space and ground systems as well. The study was USAF-centric, but there was strong Navy participation and cooperation. We believe, therefore, that our conclusions apply to Navy systems as well.

For the events and capabilities considered in the GANS study, refer to the requirements summary table at the end of this report.

Summary of Recommendations

The USAF Role in Future Airspace Architecture Design

- Restructure the USAF interaction with the Federal Aviation Administration (FAA) and International Civil Aviation Organization (ICAO) to improve both high-level and technical interaction.
- Strongly support airspace and ATC regulations based on performance.
- Strongly oppose airspace and ATC regulations based on specific hardware or software.
- Propose and support architectures and procedures that enable routine flight of uninhabited aerial vehicles (UAVs) in controlled airspace.

Navigation

- Define navigation requirements in terms of ground rather than air data quantities.
- Resist airframe and sensor modifications for Required Navigation Performance (RNP) as unnecessary and costly.
- Certify DOD GPS/INS systems to meet RNP-1 standards based on ground track.
- Survey DOD aircraft control systems and flight management systems to determine their limitations.
- Develop a precision ground proximity warning (GPW) system for DOD aircraft.

Communications

- Do not commit to civil aviation SATCOM until next-generation services are well defined.
- Collaborate with next-generation SATCOM suppliers to ensure low-cost, reliable aviation services with emphasis on military capability.
- Develop a high-frequency datalink (HFDL) for interim use in transoceanic airspace using existing DOD high-frequency (HF) equipment if possible.
- Design HFDL for dual use in VHF datalinks.
- Participate in the development of datalink standards.
- Develop civil ATC gateways for military datalinks using commercial information technology methods.
- Include the ATC network as part of the DOD worldwide command and control (C^2) system.
- Integrate civil aviation, commercial aviation, and military networks.
- Continue development of multimode radios and develop aviation versions of software-programmable radios.

Surveillance

- Develop and promote the worldwide ATC network concept to satisfy the communication and Autonomous Dependent Surveillance (ADS) needs of DOD aircraft.
- Interface tactical datalinks with ATC through offboard gateways rather than install independent civil datalink equipment in all aircraft.
- Support early adoption of ADS-A and ADS-B for surveillance and collision avoidance.
- Generate guidelines for installation of the Terminal Collision Avoidance System (TCAS) in a limited subset of military aircraft as safety considerations dictate.
- Through example and demonstration, develop methods of reducing cultural barriers to acceptance of new technology and techniques.

GPS

- Establish the USAF as the *technical* leader in establishing future enhancements for GPS.
- Develop en route and approach capabilities based on military GPS signals with civil requirements as a subset of military capability.
- Consider augmentation of the GPS constellation with six additional satellites.
- Negotiate at high levels for GPS to be accepted as the sole means of navigation and approach.
- Support GPS accuracy improvements.
- Develop a military integrity notification capability.
- Survey the future utility of GPS equipment installed under the GPS 2000 initiative.
- Plan for early termination of Selective Availability (S/A).

Approach and Landing

- Adopt GPS/INS as the primary USAF approach system for both modern and austere airports.
- Collaborate with airlines on development of a Local Area Augmentation System (LAAS) that has additional military capabilities.
- Enlist airline support for opposing the adoption of microwave landing systems (MLSs).
- Develop a bad-weather-approach design capability.

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United States Air Force Scientific Advisory Board
Global Air Navigation Systems Study

Introduction

Changes in global civil airspace architecture will necessitate changes in Air Force equipment and procedures. The Scientific Advisory Board Global Air Navigation Study attempted to identify, define, and categorize the modifications and additions necessary for Department of Defense (DOD) aircraft and ground systems to operate in the new environment in terms of urgency and utility. Many estimates of the cost of the new capabilities have been generated, and some of the estimates exceed $15 billion for all options. We believe that these estimates are not credible, and we propose an approach that is substantially less expensive. We also attempted to identify systems and technologies that can serve both military and civil needs. Participants in the study were drawn from a broad cross section of both civil and military aviation. We visited several military and civil aviation facilities, and took many briefings from and held discussions with U.S. and foreign government and commercial organizations.

Airspace architectures and global air traffic management (GATM) procedures are changing for several reasons. The density of air traffic in many parts of the world is increasing rapidly. Increasing passenger and flight volumes will force air traffic control (ATC) systems to handle volumes of traffic well beyond those for which they were designed. Some estimates predict that the existing global ATC system will become hopelessly overloaded shortly after the first decade of the 21st century. Safety is already an issue — perceived if not real — and increases in air traffic will produce increases in the number of accidents per year even if the accident rate remains constant. Efficiency of operation is always an airline concern, and the influence of this concern over national aviation authorities is increasing. It should always be remembered, however, that the Air Force exists to fight and win the Nation's wars. This mission must not be compromised in an attempt to satisfy civil airspace requirements.

Everyone's view of the future is, at best, murky. Considerations of density, efficiency, and safety can be used as general guidelines, however. Airline and USAF considerations are not necessarily different. After safety, the first decision metric used by an airline is return on investment (ROI). The important parameters that determine ROI differ among airlines, and USAF considerations may sometimes be different from those of all airlines, but ROI is closely related to efficiency of operation. Although the USAF is for the most part an unscheduled cargo airline, and its efficiency criteria are different from those of scheduled passenger airlines, many USAF flights operate during peak civil hours. The effect on the USAF of failure to comply with new civil navigation and communication standards is usually stated in negative terms. One study, for example, indicates that a 1.5-hour ATC delay per flight in a future Desert Shield scenario could increase the time to force closure by 50 percent, or 42 days. It should also be noted, however, that compliance will reduce fuel, flying hours, and the number of crews and will increase aircraft utilization.

Yet uncertain implementation plans for future international airspace architectures, especially the timing of required compliance, have made it difficult to persuade decisionmakers to fund GATM. A perceived lack of urgency and the implied existence of waivers for state aircraft have exacerbated the problem. High-priority military issues compete for limited funds. In the past we have resisted or ignored similar challenges until the threat of airspace exclusion or an accident involving loss of life forced an emergency reaction: equipping essential aircraft. These reactions were accompanied by the added expense of rushed procurement and integration. Current funding limitations make it imperative that we not repeat these mistakes. The Department of Defense operates 15,000 aircraft. All of them will be affected by changes in airspace architecture over the next 15 years. Although there is, indeed, much uncertainty in implementation plans for future airspace architectures, we found more definitive requirements than we expected. Specific requirements and dates will be discussed at the end of this paper in the section on short-term considerations.

The safety issue is one that the USAF must address in cooperation with civil aviation organizations. Controlled flight into terrain (CFIT) is a significant problem for the USAF. The T-43 “Ron Brown” crash in Croatia is probably the most publicized, but other events are troubling. The CFIT by a USAF C-130 at Jackson Hole, Wyoming; the A-10 crash in Arizona; and, perhaps, the recent B-1 low-level accident are all indications that more attention must be paid to CFIT. The civil community was galvanized by the American Airlines CFIT in Cali, Colombia; by another American Airlines incident at Hartford, Connecticut; and by the recent KAL accident in Guam. In the past five years, civil aviation has incurred more than 40 CFIT accidents at the cost of more than 2,000 lives. Perhaps the most emotional issue for the public, though, is midair collision (MAC). Close encounters between USAF aircraft and civilian airliners in the Northeast received much notice. The apparent collision between a C-141 and a German Air Force aircraft off the coast of Namibia also has been widely reported. Modern technology has matured to the point where CFIT and MAC need never occur. The issues are cost and implementation method.

It is unlikely that all USAF combat aircraft can comply with all future international regulations. It will be necessary to conduct some “fighter drag” operations in which combat aircraft are accompanied by GATM-qualified aircraft. There will be emergency situations in which aircraft will proceed with “due regard.” Contingency planning should be done for these operations. However, it should be the goal of the USAF to *use warfighting capabilities to guarantee rapid, unrestricted global access for all United States weapon systems*. Where possible, airspace requirements should be satisfied by systems that also enable military capabilities.

Rapid, unrestricted global access requires capabilities beyond those necessary for normal flight in civil airspace. For example, military aircraft must operate from austere airbases that are not equipped for all-weather civil operations. The difficulties encountered in operating into Tuzla at the beginning of the Bosnia operation are well known. The USAF response to the C-17’s shortcomings in this case was short term, technically unsatisfying, and expensive.

The GANS study examined the needs and possibilities for navigation systems to be used by the USAF of the 21st century. Departure, en route, and landing procedures and requirements were studied. It should be noted that GATM requirements will affect not only aircraft but space and ground systems as well. The study was USAF-centric, but there was strong Navy participation and cooperation. We believe, therefore, that our conclusions apply to Navy systems as well.

The discussion below will treat the long-term, most expensive issues first. Shorter-term, unavoidable modifications to existing systems will be discussed at the end of this paper.

The Air Force Role in Future Airspace Architecture Design

An important finding of the SAB GANS study group is that the USAF is in a unique position to lead the development of future international airspace architectures. The USAF can influence both the course and rate of airspace development. We cannot emphasize too strongly, however, that maintaining current architectures is not an option. Impeding progress toward improved capabilities is not an option that can succeed. The timescale and the forms of implementation are negotiable. Although the civil aviation community is frequently perceived as monolithic, nothing could be further from fact. Discussion of requirements driven by future airspace architectures is largely chaotic. Large U.S. airlines do not agree with small U.S. airlines. Regional airlines in the U.S. do not agree with long-haul airlines. National interests vary greatly. Nations that have well-established infrastructures of air traffic control, communication, and navigation systems can be expected to resist changes that result in rapid modification to their systems unless those modifications result in additional income for the infrastructure and for national carriers. Nations that have not developed such systems understand that modernization and enhancement of their capabilities are essential to their economic growth, but most are uncertain as to the optimum path. Many of these nations do not have the depth or breadth of technology to build their own systems.

Much of the international aviation community will respond positively to an independent "honest broker." In spite of much public criticism of the motives of the U.S. military establishment, the USAF has a reputation as a dedicated and competent aerospace organization that is capability driven and somewhat independent of international politics. The USAF and the Navy operate strong technical organizations that can bring unique capabilities to bear on important GATM issues. The USAF should take advantage of its reputation and its operational and technical competencies to influence international airspace development.

The USAF has been forced into a reaction mode. The resulting level of contact between the USAF and international aviation authorities is too low. USAF representatives to national and international organizations have done an excellent job of representing U.S. interests at the technical and operational levels, but senior policymaking influence is absent. Many of the aircraft and ground system modifications agreed upon by the USAF in recent years were compromises with civil organizations not necessarily in the best interests of the DOD.

We recommend that a Major Command be assigned as the primary point of contact (POC) with national and international policymaking organizations. Consideration should be given to consolidating activities and personnel that interact with the FAA, ICAO, and other technical and policymaking organizations within this command. The Air Mobility Command (AMC) is a logical choice for the contact organization. Its operations and aircraft are similar to those used in civil aviation, and the role of AMC Commander as CINCTRANS will permit all military aviation organizations to speak with one voice. It will be essential for the POC to coordinate activities with many other Air Force, Navy, and Army organizations. If the POC ignores the needs of organizations such as the Air Combat Command (ACC), the situation could worsen.

A Recommended Philosophy

There is growing acceptance in the international aviation community of the principle of establishing performance criteria rather than mandating aircraft and ATC equipment. The concepts of

RNP and Required Communication Performance (RCP) can become the future standards. It is probable that USAF requirements will meet or exceed civil performance standards, but that the equipment used will necessarily be different from that employed by civil operators. Therefore, we recommend that the USAF support and lead the establishment of standards. We also recommend that the USAF oppose continuing the process of certifying software and equipment in detail.

Procedures and requirements for the certification of aircraft and ATC systems should be considered carefully and in detail. Strong pressure exists to certify military aircraft according to FAA civil aviation regulations. For some aircraft these standards are appropriate, and in no case should safety be compromised. It is essential, however, to remember that the DOD is a certifying agency with authority equal to that of the FAA. Civil specifications are not always appropriate. At present most Navy aircraft, most USAF combat aircraft, and a significant number of USAF transport aircraft are not certified according to civil specifications. The use of DOD certification authority will be appropriate when GATM requirements are fully met by military systems that cannot be certified according to FAA standards. Similar pressures exist for the USAF to adopt a mirror image of FAA ATC systems, but it is not likely that the civil systems will suffice for USAF ATC needs. The USAF should rethink the ways in which its ATC system interfaces with the civil system. It is likely that ATC systems that provide the necessary military capability can be used to satisfy USAF obligations to provide civil ATC functions.

Although the immediate problem is related to the passage of existing and developmental aircraft through civil airspace, the USAF should not ignore the demands of the future. In particular, the increasing use of UAVs will place new demands on airspace architectures. The DOD should propose and support architectures and procedures that enable routine flight of UAVs in controlled airspace.

The limited thinking that defines capabilities in terms of equipment has recently become endemic in the USAF as well as in the civil aviation community. It must be recognized that the philosophy proposed here will force a major culture change throughout the USAF acquisition community. The alternative to the change is the expenditure of billions of dollars for a reduced military capability.

Strong support of this philosophy is not an academic exercise. Existing or planned USAF systems, such as HF radios, Link 16, and GPS/INS, can perform many of the functions that will be required in the future *if* a compatible architecture is established. The use of these systems will reduce the number and cost of new systems that must be installed. Acceptance and support of this philosophy will reduce the number of independent projects in the USAF acquisition system. It will permit the now independent project offices to work toward a common set of goals. The issues involved with the use of military systems in civil airspace will be addressed below.

The USAF Role in Future Airspace Architecture Design — Recommendations

- Restructure the USAF interaction with FAA/ICAO to improve both high-level and technical interaction.
- Strongly support airspace and ATC regulations based on performance.
- Strongly oppose airspace and ATC regulations based on specific hardware or software.

- Propose and support architectures and procedures that enable routine flight of UAVs in controlled airspace.

Operational Issues

Several major issues will determine the costs and capabilities that will result from future airspace architectures. This section discusses operational issues. Implementation time scale and acquisition strategy will be discussed separately.

In addressing operational issues, we note that the nature of modern integrated systems makes it difficult to separate individual functions. In fact it is the act of separating that leads to stovepiped projects and definitions in terms of equipment. For example, an important feature of future architectures is ADS, in which the position determined on board an aircraft is used by ATC as a replacement for radar. It is therefore necessary to determine position accurately (a navigation function) and to report that position in a reliable and timely way (a communication function). Thus, the navigation and communication functions are inseparable. In this section, however, we will plunge ahead on the dangerous task of separating functions in a way that makes the discussions of capability and time frame understandable. We understand that most military aircraft do not have integrated avionics systems. For those aircraft the definition of capability in terms of installed equipment is usually unavoidable. We emphasize, though, that the equipment definition should not be stated as a requirement, nor should equipment definition be done early in the acquisition process.

There is a belief in some organizations that operational procedures will provide “work around” possibilities that can postpone or obviate entirely the modification of aircraft. This may be true in a few, infrequent cases, such as fighter drag operations, but it should not be counted upon as a permanent solution. Aircraft that fly above FL 370 could, in principle, fly North Atlantic routes without complying with Reduced Vertical Separation Minimum (RVSM) requirements. As more aircraft become capable of flight above FL 370, though, slots at those altitudes will become more difficult to obtain. Lower altitude windows to permit climb through RVSM altitudes will also be difficult to obtain. The DOD should comply with future airspace requirements rather than search for noncompliant solutions.

Navigation. Navigation precision in aviation is sometimes defined in terms of the location of an aircraft at a specific time with respect to an accepted geographic reference. For GATM purposes it is necessary to think of navigation precision in terms of the accuracy with which an aircraft arrives at a particular point in space-time: that is, flying accurately in time is as important as flying accurately in position. One should expand the concept of a geographic, or spatial, reference frame to include time. (This point is obscured by the term “Required Navigation Performance” used to define future navigation requirements.) This fundamental of navigation will be a statement of the obvious for most readers, but it has profound implications for those who must modify or design aircraft to comply with future airspace architectures. We sometimes think of GATM in terms of information systems, but it includes the response of airframes to the information. Modification and accurate characterization of airframes, sensors, and autopilots have been necessary already for compliance with RVSM requirements on North Atlantic routes. The cost of compliance for some aircraft, such as the KC-135, is exorbitant. We believe that improvement in information systems and in the procedures enabled by those systems can reduce the extent of airframe and air data sensor modifications needed in the future. (Control system modifications may be necessary for some aircraft.)

Air traffic control standards are usually defined in terms of aircraft separation. RNP-X, where X is expressed in nautical miles, is actually a derived quantity that depends on assumptions of typical aircraft and pilot response parameters. For example, if a guaranteed en route separation of 50 nmi is needed, the navigation specification will be RNP-10. The 50-nmi separation is itself based on a separation time. Only relative arrival times at a given geographic point are needed to ensure safe aircraft separation from an ATC standpoint, but airlines, on the other hand, must specify absolute times of arrival and departure at an airport. Therefore, the relative times used by ATC are directly related to absolute time standards, and in the future absolute time standards and accuracy will become more important if the predicted advantages of increased traffic density, enhanced safety, and shorter, direct routes are to be realized. Derivation of both position and time from GPS leads naturally to absolute standards of navigation in space-time.

This somewhat esoteric discussion of navigation philosophy is directly related to both performance and cost. At present, aircraft navigation precision is related to air data quantities such as airspeed and barometric altitude. In areas where radar surveillance is possible, controllers will frequently issue instructions in terms of airspeed corrections to maintain aircraft separation. The result in a busy terminal area is that an aircraft may receive several speed corrections during arrival or departure. To qualify for RVSM routes, aircraft are required to meet minimum standards of accuracy for airspeed and altitude.

The cost of compliance for older aircraft can be high. Airspeed is a quantity derived from pressure at a sensor, and the pressure measurement can be affected by parameters other than sensor accuracy. Older aircraft can develop skin ripples that affect the airflow across a pitot tube or a static port. True airspeed determination depends on an accurate measurement of air density, usually determined from static barometric pressure, as well as dynamic pitot pressure. Older altimeters are frequently incapable of necessary accuracy at high altitudes. Correction of such imperfections can be extremely expensive. Human error is not negligible, either. The 757 crash due to tape left over pitot and static sensors was widely publicized. The accuracy standards in air data quantities needed for navigation are far higher than those needed to satisfy aerodynamic requirements. It is unlikely, however, that the use of barometric altitudes can be eliminated in the near future. Therefore, a concession to the use of barometric altitudes will be necessary in the near to mid term.

Some of the difficulties and costs related to the use of air data quantities for navigation can be avoided. In terms of absolute navigation precision related to the surface of the earth, air data is irrelevant. Speed and altitude related to navigation can be determined absolutely with respect to an earth-centric coordinate system. Air data quantities then serve as primary quantities for aerodynamic control and as backup quantities for navigation. Military GPS/INS systems can certainly provide both position and altitude precision to satisfy all currently envisioned requirements. Civil enhancements, such as WAAS, can provide similar accuracy for civil aircraft. The (now operational) WAGE and the high-accuracy EDGE differential enhancements(developed for the Joint Direct Attack Munition) are suitable for precision approach in addition to meeting all en route requirements for the next two decades. The reference of RNP standards to ground track will also permit many DOD aircraft to satisfy RNP requirements in transoceanic airspace. Integrity monitoring is an additional problem to be solved. GPS issues will be discussed in more detail later.

Political and other practical restrictions will delay the acceptance of RNP as the only requirement for navigation. For the present it will be necessary to relate capability to equipment to some extent. However, European acceptance of GPS as a sole or primary means of navigation also will be delayed for many reasons. The DOD should establish a position that military aircraft equipped with DOD-approved GPS/INS can satisfy all requirements through RNP-1. It will be necessary for the Government to support this position and for the required precision to be demonstrated, but if the argument succeeds, European navigation requirements will be satisfied through at least 2005. United States and other nations' airspace requirements are also expected to migrate to RNP-1, though no dates have yet been proposed.

Aircraft control is not independent of navigation requirements. Older aircraft autopilot systems may not be capable of the accuracy needed for precision beyond RNP-4. At the level of RNP-1 it is also questionable whether manual operation can safely meet navigation requirements. The DOD should conduct a complete survey of all aircraft to determine control system limitations in terms of RNP.

A safety issue associated with navigation is that of GPW. American Airlines in collaboration with Allied Signal and Boeing has developed a GPS-based system that depends on a terrain database carried aboard the aircraft. Display is via weather radar display in older aircraft and via the Electronic Flight Instrument System (EFIS) in newer aircraft. The system appears to work well, and its cost is reasonable. The USAF could benefit from the methods used in its design. It is likely that USAF aircraft could be equipped with more accurate and extensive terrain databases to enhance approach and landing capabilities. Indeed, recent experience indicates that a DOD GPW system may save lives. An accurate GPW system could be used for low-level terrain avoidance in military missions. A GPW system is likely to be mandated for DOD aircraft anyway, so the DOD should anticipate the requirement by developing a system with military capabilities.

Navigation Recommendations

- Define navigation requirements in terms of ground rather than air data quantities.
- Resist airframe and sensor modifications for RNP unless clearly necessary.
- Certify DOD GPS/INS systems to meet RNP-1 standards based on ground track.
- Survey DOD aircraft control systems to determine autopilot limitations.
- Develop a precision GPW system for DOD aircraft.

Communications. Communication requirements are also gravitating toward performance rather than equipment specifications. Short-term communication issues involve voice communications, and those will be discussed later. In this section we will discuss the long-term, high-cost issues.

It is certain that datalinks between aircraft and from aircraft to controller will be required world-wide in all airspace eventually. Datalinks will be used both for communications and for surveil-lance. Surveillance functions will be enabled by ADS capability aboard aircraft. (This feature will be discussed in the surveillance section following.) Here we note that once the ADS function is enabled, a high-precision collision-avoidance system can be constructed at far lower cost than the current TCAS. Communications now transmitted by voice links will be transmitted over a controller-to-pilot datalink (CPDL) at considerably higher data rates and reliability. The progression of communication requirements is not yet definite, however, although the first datalink requirements will appear for communication and surveillance along transoceanic routes.

Datalinks for operation in transoceanic airspace are *not optional*. Pacific routes will use a form of datalink by 1998, and by 2003–2005 aircraft without datalinks can expect less-than-optimum routing and increased transit times. There is, however, an option in the technical realization of datalink capability. There is pressure for all aircraft to install satellite communication systems, and it is certain that satellite communication systems will eventually be used in transoceanic aircraft. Some DOD aircraft will be equipped in the near term with military satellite communications systems for operational purposes. At present, though, civil aviation SATCOM is synonymous with INMARSAT Aviation Services. Although the system represents the state of the art in commercial SATCOM, we believe that this system is too expensive and too limited in capability to justify DOD use in the near future. The world of civil SATCOM is changing rapidly. Systems such as Iridium, Teledesic, and Celestri represent fundamental changes in SATCOM technology, operating procedures, and capabilities. The USAF should not commit to a SATCOM solution for aviation datalink, or, indeed, for operational communications, until the capabilities and limitations of the future systems become clear. In addition, the USAF should engage the corporations that are building the future SATCOM systems to guarantee that aviation issues will be addressed in their systems. The Iridium system will have an aviation component, and the systems that follow it are certain to expand that capability.

In the interim we believe that HFDL has much to offer. The data rates needed during the next 5 years are low. Many DOD aircraft have HF radios already installed, and the data rates needed can be provided by a modem no more complex than those used in home personal computers. The HFDL will provide addressing of messages to individual aircraft, and continuous monitoring of an HF frequency will no longer be necessary. Encrypted messages can be transmitted with high probability of correct reception. Preliminary experiments with prototype HFDL systems are producing encouraging results with first-try contact rates approaching those of SATCOM. The USAF should investigate the cost and the performance of this system as an interim substitute for SATCOM.

If HFDL proves adequate for long-distance communications in the near term, the message-forming and display equipment should be useful for future VHF datalinks. Design of HFDL systems should keep this future application in mind. Requirements for future VHF systems are not firmly established, and dual use of portions of HFDL should prove attractive to airlines as well as to the DOD.

The DOD has developed datalink systems for military aircraft with the primary link being Link 16. A Joint Tactical Datalink Management Plan (JTDLMP) has been established with the goal of providing a “seamless, flexible datalink environment.” Many billions of dollars will be spent on these systems by the time all appropriate platforms are equipped, and the military datalink systems have capabilities far beyond those needed for civil GATM purposes. It would be counterproductive, expensive, and, we believe, unnecessary to install additional, less capable systems to comply with civil airspace requirements. Functions such as Mode-S may be possible from Link 16 systems with small modification. In general, however, the frequencies and data structures are not universally compatible with civil systems. An additional discussion of this point will appear in the surveillance section. We observe that it may be less expensive to provide military datalink interfaces, or gateways, with ATC organizations than to install additional equipment in all DOD aircraft. Networking of

ATC facilities, as described below, will further reduce the cost of integrating military tactical datalinks with civil ATC authorities. Integration of dissimilar systems is a common, almost routine, task in civil information technology. The DOD should take advantage of existing methods.

In addition to the issues associated with the physical implementation of datalinks, there is substantial disagreement (disconnect may be a better description) over standards, message content, and recommended practices. The Radio Technical Commission for Aeronautics (RTCA) has established standards for ADS and CPDLC. These standards are not completely followed in FANS-1, and the ICAO proposals are significantly different. The USAF could contribute in a significant way to the resolution of these discrepancies. Datalink standards should be designed to accommodate international UAV flights in controlled airspace.

The Navy requirements for communication between tactical aircraft and civil ATC organizations are likely to be less stressing than USAF requirements. Networking of ATC communications from aircraft through a ship to land-based ATC using interfaces similar to those appropriate for the USAF may be an attractive solution.

The DOD is developing new worldwide C^2 facilities. A natural augmentation of these would be ATC network communication and gateway facilities. An advantage for the C^2 system is that ATC information would be immediately available for mission planning and inclusion as part of a global awareness function. Management of UAV flights in controlled international airspace would be enabled by inclusion of ATC in the C^2 system.

The commercial equivalent of the worldwide C^2 system is the Global Grid. Integration of civil aviation, commercial aviation, and military networks will provide a robust capability for everyone. Of course, security requirements must be met.

Although most DOD aircraft have federated communication systems, newer aircraft, such as the C-17 and F-22, were designed with highly integrated systems. Non-recurring costs associated with modification of integrated systems are very high. The DOD can realize substantial cost savings if modifications are done in a way that prepares the groundwork for future systems. The software-programmable and multimode radios are examples of such development. Multimode RF system development should be continued. Although software-programmable radio development is proceeding in the Speakeasy program, it is unlikely that Speakeasy can be certified for aviation use. Aviation requirements, particularly related to operating system performance, should be developed.

Communications Recommendations

- Do not commit to civil aviation SATCOM until next-generation services are well defined.
- Collaborate with next generation SATCOM suppliers to ensure low-cost, reliable aviation services with emphasis on military capability.
- Develop HFDL for interim use in transoceanic airspace using existing DOD HF equipment if possible.
- Design HFDL for dual use in VHF datalinks.
- Participate in the development of datalink standards.

- Develop civil ATC interfaces for military datalinks using commercial information technology methods.
- Include the ATC network as part of the DOD worldwide C^2 system.
- Integrate civil aviation, commercial aviation, and military networks.
- Continue development of multimode radios and develop aviation versions of software-programmable radios.

Surveillance. Surveillance requirements in future airspace architectures will transfer to the aircraft many functions now performed on the ground at ATC facilities. Position will be determined aboard the aircraft using GPS, reported to ATC on command, and broadcast to other aircraft in the vicinity. The commanded report is usually identified as Autonomous Dependent Surveillance — Addressed (ADS-A) and the general broadcast as ADS — Broadcast (ADS-B). Although radar will be used for tracking aircraft throughout the foreseeable future, the self-determined position will be more accurate and more reliable. ATC radar will increasingly become an anachronism. The aircraft will perform many collision avoidance functions with high reliability independent of ATC. Because of the use of onboard computers, the overall computational capability of the integrated ATC system will increase dramatically. There will remain a need for close integration of aircraft and ground functions, and the integration of ATC facilities must be more complete than at present. Today, many ATC communications between facilities are by telephone. A controller may spend as much as one-third of his or her time coordinating by voice with other facilities. The need for more efficient collaboration between control centers offers opportunities for the USAF.

The USAF is a major supplier of ATC services for both civil and military aircraft, and ATC facilities also exist aboard ship. In fact, facilities similar to civil ATC installations exist in many places, often with identical equipment, but mobile systems for austere bases and naval applications may be quite different from their civil counterparts. To take advantage of the commonalities and overcome the discrepancies, the DOD can approach solutions to ATC problems created by future architectures as an equal partner with national ATC suppliers. In fact, the USAF ATC system is larger and far more complex than those of many nations.

We believe that the key to efficient use of all ATC facilities is to provide an international, redundant ATC network analogous to the Internet. Controller workload will be reduced substantially by instantaneous data communications with other installations worldwide; worldwide traffic flow information will be available instantly to all participants.

The most important feature of an ATC network is that data from aircraft can be injected into the network at many points and addressed to the proper recipient. It is not necessary that a transmission be received directly by the using facility. Many ATC facilities, such as the FAA Air Route Traffic Control Centers, use remote radar and communication installations, but the network concept is quite different. Remote installations are typically connected by dedicated lines to a controlling facility. A network permits transmissions received by a single antenna to be sent directly to many different receiving facilities. Thus, airlines and military units can monitor their aircraft in real time through the ATC network without establishing independent communication systems. Alternatively, if private networks are established, they can be used as emergency backups for the public ATC system. A network will, for example, permit an encrypted, low-probability-ofintercept, Link 16 transmission from a USAF F-16 to German ATC in, say, Frankfurt to be placed on the network at Rhine Main and transmitted to a gateway at Ramstein, where it will be decrypted, formatted according to German ATC protocol, and placed back on the network addressed to the proper civilian controller at Frankfurt. As far as the controller and the pilot are concerned, Link 16 provides a transparent data interface between the F-16 and civil ATC. The intermediary could have been an AWACS, a Navy ship, or a mobile ground communication facility. Security enhancements or restrictions can be applied at the gateway in a dynamic fashion according to current orders that change with the world or with local political conditions.

We believe that the network concept enables and encourages innovation and will result in significant cost savings, enhanced force security, and improved military capability. For example, direct communications between, say, an F-16 and an F-18 over the horizon will be clear and instantaneous. We do not minimize the cultural barriers that will be raised, but we believe that the technology-enabled enhancements and cost reductions for the civil community as well as for the military community will eventually carry the day.

A surveillance-related capability that has received much attention recently is TCAS, a rudimentary system that interrogates aircraft Mode-C and Mode-S transponders in its vicinity and determines whether possible conflicts exist. If a collision is possible, TCAS issues a maneuver order to the pilot according to a universal algorithm. Altitude is determined from transponder response, but no azimuthal information is available. Therefore, only vertical maneuvers can be generated. There is pressure on the DOD to install TCAS on all passenger-carrying aircraft, and it is probable that the Namibia collision could have been prevented if the C-141 had been equipped with TCAS. It is likely that the standard TCAS system will be mandated for VIP aircraft, but it should be observed that ADS-B or ADS-A repeated to all aircraft will satisfy all TCAS requirements and provide azimuthal avoidance as well. A subset of USAF aircraft will need TCAS equipment in the near term. A safety analysis of the utility of TCAS for aircraft that primarily carry passengers or operate routinely in congested civil terminal areas should be conducted. The study will generate a baseline for voluntary, near-term TCAS installations. A rough estimate indicates that 10 percent of DOD aircraft may require TCAS in the near term. We recommend, though, that ADS methods be pursued as a TCAS alternative in the long term.

Surveillance Recommendations

- Develop and promote the worldwide ATC network concept to satisfy the communication and ADS needs of DOD aircraft.
- Interface tactical datalinks with ATC through offboard gateways rather than install independent civil datalink equipment in all aircraft.
- Support early adoption of ADS-A and ADS-B for surveillance and collision avoidance.
- Generate guidelines for installation of TCAS in a limited subset of DOD aircraft as safety considerations dictate.
- Through example and demonstration, develop methods of reducing cultural barriers to acceptance of new technology and techniques.

The Global Positioning System

The U.S. military possesses and controls a jewel of great value known as the Global Positioning System. The GPS provides positioning and timing information to military and civil organizations worldwide, and it has become entwined in our daily lives in ways not always apparent. Most of the applications of GPS that have been publicized are derived from the civil, or C/A, signal from the GPS satellites. Most of the innovation and technology developments are more useful for the civil user than they are for the military user. Development of new techniques and equipment for the military user have, sadly, lagged far behind those appropriate for civil users.

In spite of the slow development of military applications and capabilities compared to those of the civil sector, the U.S. military has become dependent on GPS for a significant fraction of its war-fighting capabilities. It is well known that precision weapons employing GPS guidance have achieved unparalleled accuracy at low cost. It is less well known that systems thought to be independent of GPS are not. For example, Link 16, a time-division, multiple-access system, derives its timing standard from GPS.

For GANS applications the military segment of the GPS has many advantages over the civil segment. The FAA is developing the Wide Area Augmentation System (WAAS) to improve the performance of GPS to a level appropriate for CAT I approaches. WAAS compensates for inaccuracies introduced by S/A and ionosphere delay and provides constellation integrity information. Military accuracy enhancements, such as WAGE, added to the standard two-frequency military signal provide accuracy exceeding that of WAAS without extensive, costly, ground-based monitoring systems. Autonomous integrity monitoring coupled with inertial measurement and further improvements in accuracy through methods such as the EDGE system demonstrated for JDAM and developmental bombs can provide accuracy, availability, and integrity monitoring at levels approaching those required for CAT III operation. Availability of accuracy at these levels is likely to be lower than that required for commercial airline operations at all hours of the day, but the capability will be available everywhere in the world no matter how austere the base. Availability is also a deterministic quantity that can be ascertained well in advance of a flight so that arrivals can be scheduled accordingly. GPS augmentations that provide only integrity are far simpler and cheaper than those that provide civil accuracy enhancements. It is possible that integrity information can be provided in a timely way through future SATCOM or even HFDL. The provision of a military integrity signal should be investigated.

The existing GPS consists of a constellation of 24 satellites. For autonomous determination of integrity during approach, 24 satellites provide a marginal capability. The addition of 6 satellites and the repositioning of the remaining 24 will improve the situation greatly. Jamming susceptibility is also reduced when more satellites are in view. Additional advantages will accrue to the civil users as well. The USAF should seriously consider the addition of another 6 satellites in the long term. Studies of satellite orbits and replacement times exist and are well documented.

The susceptibility of GPS to jamming is well known and highly publicized. Jamming of signals for communication and surveillance is always an issue to be addressed in a theater of war, so one should keep the problem in perspective. For example, the military GPS signal is less susceptible to jamming than an Instrument Landing System (ILS) signal, and it is not susceptible to spoofing. For transport applications the GPS/INS solution based on an enhanced military GPS with additional antijam enhancements will suffice for all en route and, at least, CAT I approach needs;

antijam performance equal to that of current NAVAIDS can be expected. It is important, however, that the DOD not accept navigation and approach capabilities based on civil signals and equipment as the solution to military needs. It may be necessary to install a capability for using civil enhancements, such as the European EGNOS system, but these should be part of the integrated military system. *Civil performance must be a subset of military capabilities, not a replacement for military capabilities.*

Warfighting requirements demand GPS/INS for all DOD aircraft. Systems that meet military needs can easily satisfy civil requirements at no additional cost if those capabilities are designed into the systems procured for military aircraft. The GPS 2000 initiative is an important opportunity to provide superior GPS-based performance for all DOD platforms. Unfortunately, planning and procurement have been fragmented. It is possible that many of the systems installed or planned for installation will be inadequate for basic functions, and many cannot be upgraded. The Air Force, Navy, and Army should survey the quality and capabilities of equipment installed, or planned, to satisfy the GPS 2000 initiative, comparing them with current civil capabilities. Jamming susceptibility should be quantitatively determined, as should the appropriateness of the equipment for future civil airspace and military use. The practice of procuring GPS individually for each platform must be discontinued. The result has been uneven requirements definitions and highly variable performance at high cost.

Civil airspace considerations will make it impossible for military aircraft to use military GPS for en route and approach guidance in civil airspace unless GPS is accepted worldwide as the sole or at least primary means of navigation. Certainly the performance of a closely coupled GPS/INS will exceed the performance of any existing or planned navigation or approach system. The users of navigation services are already using GPS whether approved by an ATC authority or not. One Eurocontrol official referred to GPS as a “tide that cannot be stopped.” The GPS users simply carry the required non-GPS equipment and ignore it. The political situation, however, is slowing acceptance. The concept of RNP is gaining support, though, and one can argue that only performance now matters. It may be true that system details will not be scrutinized in detail in the future, but it is too much to hope that navigation based on phenomena different from those used by the civil community will be approved for use in civil airspace. In the interest of performance and cost, it is incumbent on the USAF to argue and negotiate strongly for worldwide approval of GPS.

Negotiation will be necessary. The DOD should be prepared to provide additional capability and assurances to the civil community in exchange for acceptance. Discontinuing S/A is a valuable bargaining chip; the military utility of S/A is questionable at best. Adding one more civil frequency is another bargaining position. Distribution of additional integrity information and involving the international aviation community in GPS operations would be valuable contributions as well. The GPS III study will define future GPS capabilities, and its progress should be followed closely.

Whether or not S/A can be exchanged for international concessions, the Air Force should plan for its early termination. The inaccuracy introduced by S/A raises questions of both flight safety and international acceptance. The WAAS could be made much more reliable if it did not have to compensate for S/A. The approaching solar maximum makes it important to increase the link margin for WAAS and similar international systems. The robustness of the GPS control segment should be improved before solar max.

GPS Recommendations

- Establish the USAF as the technical leader in establishing future GPS enhancements.
- Develop en route and approach capabilities based on military GPS signals with civil requirements as a subset of military capability.
- Consider augmentation of the GPS constellation with six additional satellites.
- Negotiate at high levels for GPS to be accepted as the sole means of navigation and approach.
- Support GPS accuracy improvements.
- Develop a military integrity notification capability.
- Survey the future utility of GPS equipment installed under the GPS 2000 initiative.
- Plan for early termination of S/A.

Approach and Landing

Military needs for approach and landing capabilities substantially exceed those of the civil community. The USAF must have a worldwide capability for precision approach independent of local ground equipment. Absence of that capability led to embarrassment for the United States at the beginning of the Bosnia Peace Accord Operation. If the military situation on the ground had been more critical, loss of life could have occurred as a result of the delay in landing supplies. Even when local airports have rudimentary NAVAIDS, as in Dubrovnic, disaster can occur. It is clear that the USAF needs a self-contained approach capability for many of its aircraft. We believe that this need can be met by the GPS described above. In the near term, a LAAS may be useful.

There is competition for acceptance of GPS/INS as an approach system. MLSs will be installed at a few airports in Europe. British Air and KLM favor MLS for installations at Heathrow and Schipol mostly to ensure the primacy of British Air and KLM at those important airports, but there have been reports of unsafe disturbance of ILS CAT III signals at Schipol. GPS has a decided accuracy and cost advantage over MLS. It is useful for both en route and approach operations. It will probably result in safer operation as well, but safety studies must be done. It is not certain that an MLS requirement for some European operations can be forestalled, but it is worth a try. Non-European airlines should be willing allies in the negotiations because of the high cost of aircraft modification.

U.S. airlines appear to support LAAS for satisfying CAT III requirements. LAAS is certainly a lower-cost and more useful solution than MLS. LAAS can also provide taxi guidance during periods of low visibility, or even in zero-zero conditions.

As an auxiliary issue, a facility for designing approaches in bad weather must be developed. The Air Force has the equipment; it is mostly a matter of developing a CONOPS and testing the procedure.

Approach and Landing Recommendations

- Adopt GPS/INS as the primary USAF approach system for both modern and austere airports.
- Collaborate with airlines on development of a LAAS that has additional military capabilities.
- Enlist airline support for opposing the adoption of MLS.
- Develop a bad-weather-approach design capability.

Near- and Midterm Schedules

We found that several of the near- and midterm implementation schedules were firmer than we had believed. Here we will summarize proposed schedules and indicate their certainty or lack of it.

Certainties

The following implementations are certain enough that the DOD should appropriate funds for aircraft modification.

1. RVSM. Already implemented on North Atlantic tracks between FL 330 and FL 370. Planned above FL 290 in March 1998, but de facto implementation will occur earlier as the result of the program's apparent success. Pacific and continental U.S. (CONUS) implementation by 2001 is uncertain, but success in the North Atlantic may hasten or stabilize the date.
2. 8.33-kHz VHF channels will be required for operation in Europe by 1 January 1999. UHF may suffice for military aircraft for a short period. UHF should not be considered a permanent solution.
3. Mode-S level 2. Required in Europe for new aircraft 1 January 2001, and for all aircraft by 2003.
4. RNP-10. Required in the Pacific between FL 290 and FL 410 in 1998.
5. RNP-5 (BRNAV). Required in Europe in 1998.
6. Protected ILS. Required in Europe in 2001 (could be delayed by strong opposition).

Less Certain Implementations

Dates have been established for the following implementations, but delays are almost certain. Strong leadership from the USAF could delay or modify proposed systems or implementation dates. Budget planning is believed optional until requirements stabilize.

1. WAAS. Planned for IOC 1998 and FOC 2001.
2. Flight 2000 demo. May be canceled entirely.
3. Decommissioning of ground NAVAIDS.
4. ADS implementations (ADS-B should be supported by the USAF if GPS-based).

5. Mode-S levels 3 and 4.
6. RNP-4 by 2000 in the North Atlantic and by 2003 in the Pacific.
7. RNP-1 in Europe by 2005.
8. LAAS by 2001 in CONUS. May occur earlier than WAAS in a few locations.
9. SATCOM required by 2000 in the Atlantic and 2003 in the Pacific. (Propose delay to incorporate new satellite technology.)
10. VHF datalink by 2005 in Europe and CONUS.
11. Free flight.

Acquisition Strategy

The modification of aircraft to satisfy both civil and military GATM requirements will be costly. It is certain that the solutions will be completely unaffordable if each platform program office is left to define compliance. GANS implementations should be treated as a system of systems. A single program office should be established to oversee the entire DOD compliance program. Budget control should rest in the single program office. A single allocation will provide flexibility in design and installation of aircraft systems. It will also permit flexible transfer of funds from one platform to another if one platform encounters delays. Therefore, common solutions that apply to more than one platform should be sought, and the natural tendency to overdesign must be resisted. For example, the installation of a glass cockpit in the C-141 as part of GPS 2000 compliance led to a useful capability, but its justification was somewhat tenuous. The cost was higher by a factor of ten than the cost of GPS installation alone.

It is certain that compliance with most of the near-term certainties using the customary DOD planning and acquisition process will be extraordinarily difficult if not impossible. Timely compliance requires a close partnership between U.S. defense contractors and the DOD. It will probably be necessary to obtain legislative relief from many DOD contracting regulations; authority similar to that enjoyed by the FAA should be sought.

Other innovative acquisition options should be explored. The DOD could offer a fee-for-service contract in which the service is provision of global access for DOD aircraft. Commercial financing options should also be explored.

Although time is short for implementation of some capabilities, other, longer-term capabilities may benefit from demonstration. A commitment to demonstrate contested implementations of GANS capabilities may place the USAF in a technical leadership position. A planning and installation time of 5 years or less should be established as a goal.

Civil aviation solutions and costs should be monitored closely, and commercial equipment should be used when possible. It must be remembered, however, that military capability is the goal. That goal must not be sacrificed on the altar of financial or schedule immediacy.

Requirements Summary

The events and capabilities considered in the GANS study are shown in the accompanying table. The implementation dates suggested by the agency recommending the capability or equipment is shown in the second column. Our assessment of the probability that the implementation will actually occur on the suggested date is given in the next column. The probability is a qualitative conclusion reached after discussion and reflection; it can change if new political deals are struck. The recommended action is based on the principles discussed in this report. The probable outcome depends on the DOD's engaging in spirited discussion at both high and technical levels. If the outcome predictions are accurate, the cost of GANS compliance will be much lower than currently forecast.

Summary of Requirements and Significant Events With Suggested USAF Actions

Event or Requirement	*Date*	*Prob*	*Recommended USAF Action*	*Probable Outcome*
RNP-10 (PAC)	98	High	Comply if GPS/INS-based. Else argue for delay	Delay or success
RVSM (ATL)	98	High	Comply — steer to GPS/INS basis	
WAAS IOC (US)	98	Med	No action. NAVAIDS available until 08	
RNP-10 (PAC)	98-00	High	Support if GPS/INS-based	Success
RNP-5 (BRNAV) (EUR)	98	High	Comply if GPS/INS or VOR/DME-based	Success
8.33-kHz VHF (EUR)	99	High	Comply but propose UHF interim	Required; some use of UHF may be possible
RVSM (PAC)	00	Med	Comply if GPS/INS-based	Delay or success
ATN	00	Low	Modify for DOD gateway	Delay, success
Flight 2000 (US)	00	Low	Participate if funded	No action
RVSM (US)	00	Low	Support if GPS/INS-based	Success
TCAS (EUR)	00-05	Med	Oppose if USAF compliance required	Success. Probable mandate for passenger aircraft
Protected ILS (EUR)	01	High	Oppose	Forced compliance
GPS Landing	01+	Low	Oppose until reasonable using military GPS	Delay or success
CNS (PAC)	03	Med	Comply, but with delay if HFDL, GPS/INS	Success. Probable delay until 06
HFDL (PAC)	03	High	Support	Success
SATCOM (PAC, US)	03	Med	Propose delay to evaluate new SATCOM, e.g., Iridium	Success. New SATCOM probable winner
CPDLC (PAC)	03	Med	Support HFDL, oppose SATCOM	Success
ADS-A (PAC)	03	Med	Delay unless HFDL-based	Success
RNP-4 (PAC)	03+	Med	Comply if GPS/INS-based	Success
Mode-S level 2 (EUR)	03	High	Comply to level 2 — suggest delay	Forced compliance
NEXCOM (US)	04-10	Low	Include DOD gateway	Success, delay
VHF DL (EUR, US)	05	Low	Propose DOD gateway, else oppose	Success with delay
RNP-1 (EUR)	05+	Med	Comply if GPS/INS-based — otherwise oppose	Delay
NAVAID, CAT I Decom (US)	08	Low	Comply if GPS/INS-based	Success or delay
ADS-B	08-12	Med	Support if satisfied by DOD systems	Success
ADS-B (US)	08	Med	Support with gateway	Success
CAT II, III Decom	10	Low	No action. Need USAF decision on implementation	
Mode-S level 3, 4	10+	Low	Oppose strongly	Indefinite delay
Secondary radar decom	14	Low	No action	

Conclusion

This paper is a summary of the conclusions and observations reached by the SAB GANS study group. A more detailed discussion of options will be given in the final report. Major conclusions and recommendations are not expected to change.

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